automotive electrical systems review

Preview to Select STST Courses

STST
Service Technician Specialty Training
Ford
Ford Parts and Service Division
Technical Training

IMPORTANT SAFETY NOTICE

Appropriate service methods and proper repair procedures are essential for the safe, reliable operation of all motor vehicles, as well as the personal safety of the individual doing the work. This manual provides general directions for accomplishing service and repair work with tested, effective techniques. Following them will help assure reliability.

There are numerous variations in procedures, techniques, tools, and parts for servicing vehicles, as well as in the skill of the individual doing the work. This manual cannot possibly anticipate all such variations and provide advise or cautions as to each. Accordingly, anyone who departs from the instructions provided in this manual must first establish that he compromises neither his personal safety nor the vehicle integrity by his choice of methods, tools or parts.

As you read through the procedures, you will come across NOTES, CAUTIONS, AND WARNINGS. Each one is there for a specific purpose. NOTES give you added information that will help you to complete a particular procedure. CAUTIONS are given to prevent you from making an error that could damage the vehicle. WARNINGS remind you to be especially careful in those areas where carelessness can cause personal injury. The following list contains some general warnings that you should follow when you work on a vehicle.

- Always wear safety glasses for eye protection.
- Use safety stands whenever a procedure requires you to be under the vehicle.
- Be sure that the ignition switch is always in the OFF position, unless otherwise required by the procedure.
- Set the parking brake when working on the vehicle. If you have an automatic transmission, set it in PARK unless instructed otherwise for a specific service operation. If you have a manual transmission, it should be in REVERSE (engine OFF) or NEUTRAL (engine on) unless instructed otherwise for a specific service operation.
- Operate the engine only in a well-ventilated area to avoid the danger of carbon monoxide.
- Keep yourself and your clothing away from moving parts when the engine is running, especially the fan and belts.
- To prevent serious burns, avoid contact with hot metal parts such as the radiator, exhaust manifold, tail pipe, catalytic converter and muffler.
- Do not smoke while working on the vehicle.
- To avoid injury, always remove rings, watches, loose hanging jewelry, and loose clothing before beginning to work on a vehicle. Tie long hair securely behind the head.
- Keep hands and other objects clear of the radiator fan blades. Electric cooling fans can start to operate at any time by an increase in underhood temperatures, even though the ignition is in the OFF position. Therefore, care should be taken to ensure that the electric cooling fan is completely disconnected when working under the hood.

The recommendations and suggestions contained in this manual are made to assist the dealer in improving his dealership parts and/or service department operations. These recommendations and suggestions do not supersede or override the provisions of the Warranty and Policy Manual, and in any cases where there may be a conflict, the provisions of the Warranty and Policy Manual shall govern.

The descriptions, testing procedures, and specifications in this handbook were in effect at the time the handbook was approved for printing. Ford Motor Company reserves the right to discontinue models at any time, or change specifications, design or testing procedures without notice and without incurring obligation. Any reference to brand names in this manual is intended merely as an example of the types of tools, lubricants, materials, etc. recommended for use. Equivalents if available may be used. The right is reserved to make changes at any time without notice.

Produced and Coordinated by
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Technical Training
Ford Parts and Service Division

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COURSE OBJECTIVE

The purpose of this precourse book is to review the material on automotive electronics that was presented in the Service Technicians Specialty Training Course on Electrical Systems.

The subjects to be covered are:

- Introduction to Electronics
- Basic Circuit Construction
- Electrical Measuring Devices
- Electrical Components
- Charging System Components

INTRODUCTION

Automotive electrical and electronic systems have long been viewed as a technician specialty field. As the components and systems have increased in complexity, the diagnostic skills required have also increased. For this reason, an increasing number of technicians are dropping out of this specialty area.

Opportunities exist at many dealerships for those technicians who are knowledgeable in vehicle electrical systems. The ability to diagnose and perform repairs on the electrical systems quickly and accurately increases the value of the technician.

As we get farther away from mechanical sensors and controls, and begin to use more electrical and electronic systems, it becomes more important for technicians to have a working knowledge of electricity.

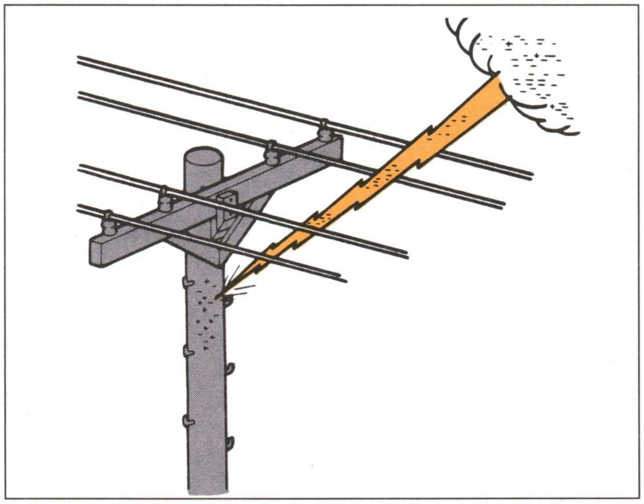
WHAT IS ELECTRICITY

Electricity is difficult to define, though its effects are all around us. As simply as we can put it, electricity is a natural or man-made condition in which there are **positive** and **negative charges** capable of causing the movement of electrons from one body of matter to another.

A basic physical law says that:

- Like charges repel
- Unlike charges attract

Therefore, if we create a substantial difference in positive and negative charge between two points, and a path for flow, electricity will move and something will happen.



DIFFERENCE IN CHARGES

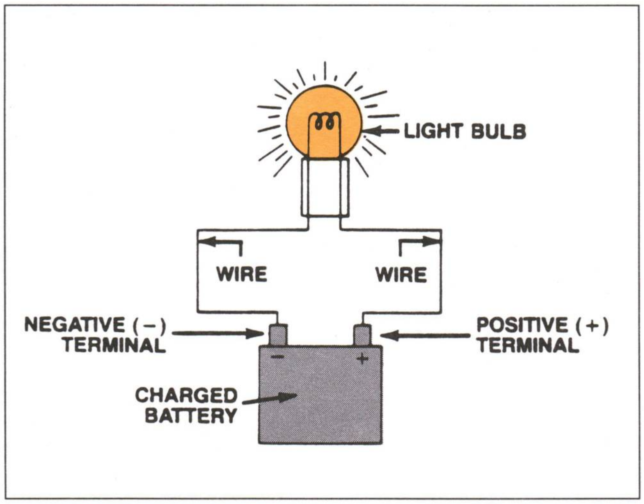
Electricity was not invented. It was discovered. Electricity has always existed as lightning, magnetism, static, etc. The inventors in the field of electricity are those who have created devices that can control electricity to perform a certain function. These devices include Thomas Edison's light bulb and the phonograph.

ELECTRICAL TRANSMISSION OF POWER

Electricity can be transmitted along wires and other conductors, through electrical circuits, to do work. It can be used to produce:

- Light (bulbs and lamps)
- Sound (horns, buzzers)
- Rotary motion (motors, starters)
- Linear motion (solenoids)
- Heat (electric defrosters)

The movement of electricity along a **conductor** is called **electron** flow or **current** flow. It uses a measurable amount of **power** to do the work.



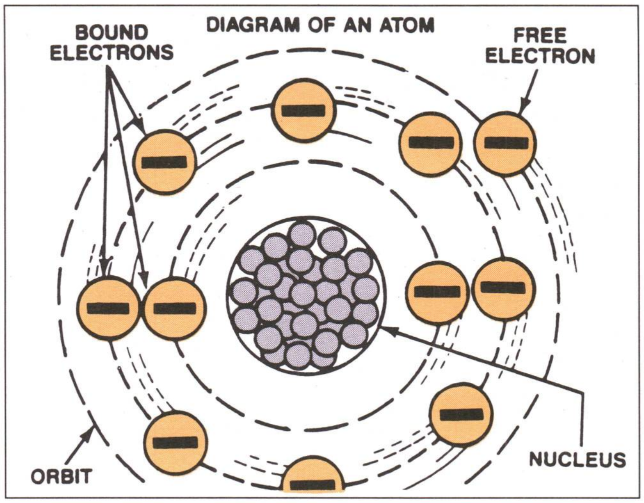
BASIC ELECTRICAL CIRCUIT

ATOMS AND ELECTRONS

Everything that has substance and takes up space, whether it is solid, liquid, or gas, is made up of very tiny particles called **atoms**. An atom is the smallest identifiable particle of a specific element.

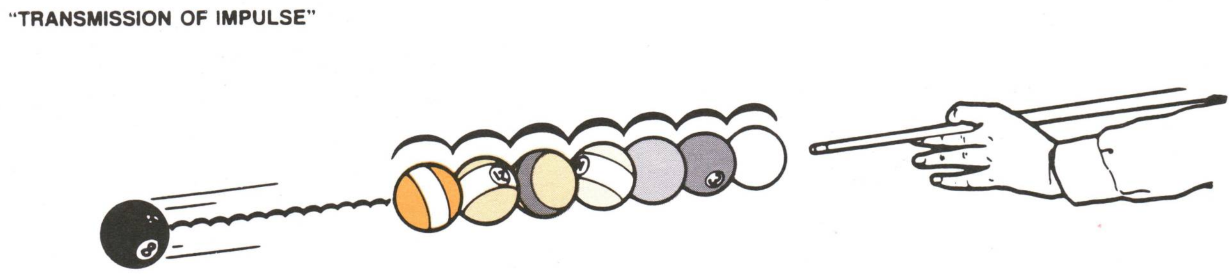
Scientists believe that all atoms have negatively charged particles, known as **electrons**, which revolve around a central core, or **nucleus**. The nucleus is believed to be positively charged, and to contain protons and neutrons.

Electrons in the inner orbit or orbits are known as bound electrons. Those in the outer orbit are called **free electrons**. It is believed that the free electrons can be easily forced out of their orbits, causing an electron flow from one atom to another.



BOUND AND FREE ELECTRONS

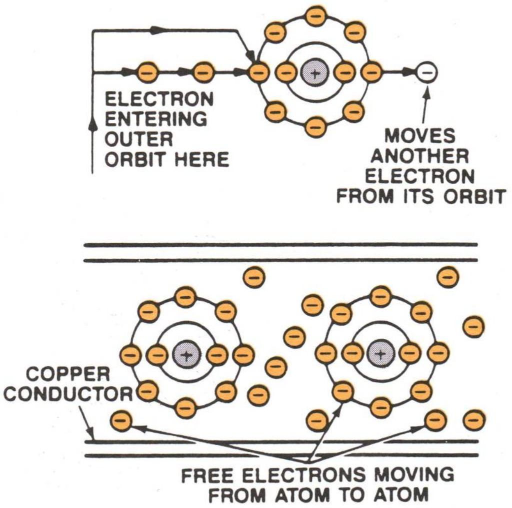
CURRENT FLOW



TRANSMISSION OF IMPULSE

ELECTRON THEORY

The "electron theory" states that current flow is the organized, forced movement of free electrons in a specific direction.


ELECTRON ENTERING OUTER ORBIT HERE
MOVES ANOTHER ELECTRON FROM ITS ORBIT
COPPER CONDUCTOR
FREE ELECTRONS MOVING FROM ATOM TO ATOM

ELECTRON DRIFT

- If the flow is continuous in one direction only, it is called **direct current** or **DC**.
- If the flow alternates back and forth in direction, it is called **alternating current** or **AC**.

A good conductor is a material, such as copper, that has many free electrons and readily transmits electricity. The force that causes the electrons to move from one atom to the next is called **electromotive force** or **EMF**. It is caused by a difference in electrical potential, and is measured in **volts**: thus it is often referred to as simply **voltage**.

When the electrons begin to flow, the effect is felt instantly all along the conductor, very much as force can be transmitted through a row of billiard balls, as shown. The speed is the same as the speed of light: 186,000 miles per second.

POWER "FLOW" OR SIGNAL "FLOW"

In automotive electricity (and in all electronics), it is conventional to consider "potential" or power "flow," or the "flow" of an electrical signal, as being from 1 to negative. A positive condition is a higher "potential," negative or less positive is lower "potential."

- Thus, circuits are usually traced from the source, to the load, and then to ground. In a negative-ground system, power is assumed to "flow" from positive to negative.
- Similarly, in all negative-ground systems, a voltage **signal** is positive. Signals also are traced or "flow" from positive to negative.

In actual fact, only current flows. The "flow" of power or of a signal is merely an assumption to aid in tracing what goes on in a circuit.

THE BASICS OF ELECTRICITY

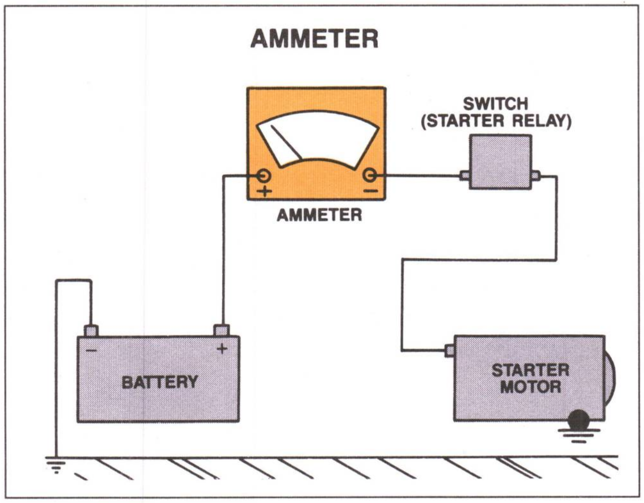
PRINCIPAL ELEMENTS OF ELECTRICITY

The three principal elements of electricity are current, voltage, and resistance.

Current

Current is the flow of electricity through the electrical system of a vehicle.

Current is measured in **amperes** or **amps**. The letter **A** is used as the symbol for amps.

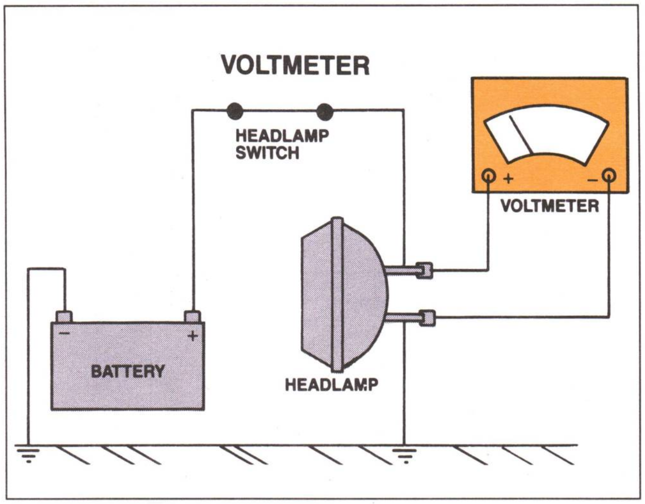


CURRENT

Voltage

Voltage is the electrical force or pressure that causes the current to flow through an electrical circuit.

Voltage is measured in **volts.** The letter **V** is used as the symbol for volts.

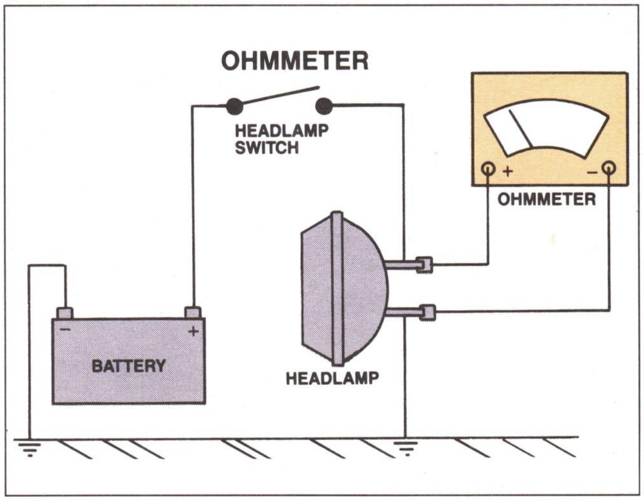


VOLTAGE

Resistance

Resistance is the opposition to current flow in an electrical circuit.

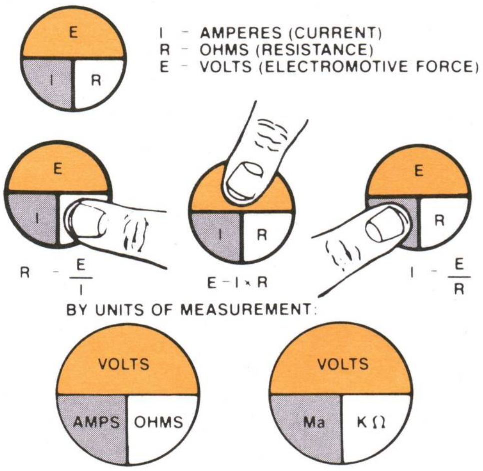
Resistance is measured in **ohms**. The Greek letter omega Ω is used as the symbol for ohms when writing specifications, but in other applications, the letter **R** is used to indicate resistance.



RESISTANCE

OHM'S LAW

Ohm's Law is the basic rule that shows the relationship among the three elements of electricity. It provides a group of formulas to find missing values in testing for an electrical problem.



OHM'S LAW FORMULA

OHM'S LAW FORMULAS

The three formulas of Ohm's Law are:

1. **Amps equal volts divided by resistance.**
2. **Volts equal amps multiplied by resistance.**
3. **Resistance equal volts divided by amps.**

If any two of the values are present, the third value may be found by using Ohm's Law.

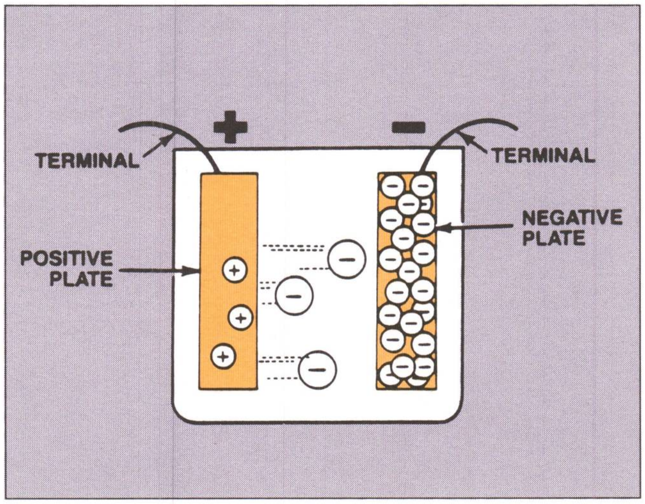
SOURCES OF ELECTRICITY

There are several sources or ways of producing electricity. On automotive vehicles, the sources for electrical circuits are the battery and the alternator. But anything that causes electrons to move can be an electrical source.

BATTERY

A **battery** is a chemical source of electricity. It contains a number of positive plates and an equal number of negative plates. The plates are immersed in a solution of water and sulfuric acid. The plates are lead compounds; thus it is often called a lead-acid battery.

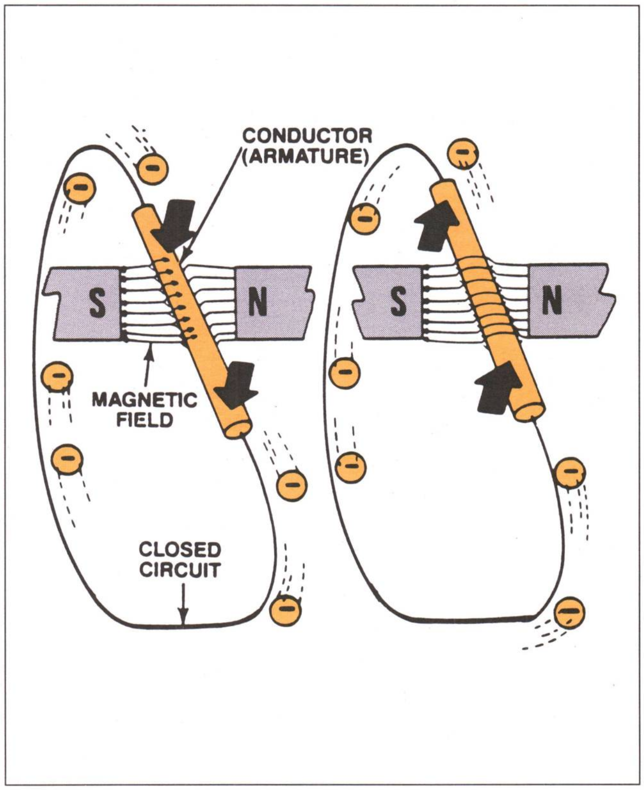
When the battery is charged, a chemical reaction of the acid on the plates results in an excess of electrons collecting on the negative plates. If a conductor is connected between the two terminals, current will flow.



BASIC BATTERY

GENERATORS AND ALTERNATORS

When a conductor, connected to a closed circuit, moves through a **magnetic field**, electric current or voltage is generated. This is the principle of **electromagnetic induction**. Generators and alternators use this principle for operation.



INDUCTION

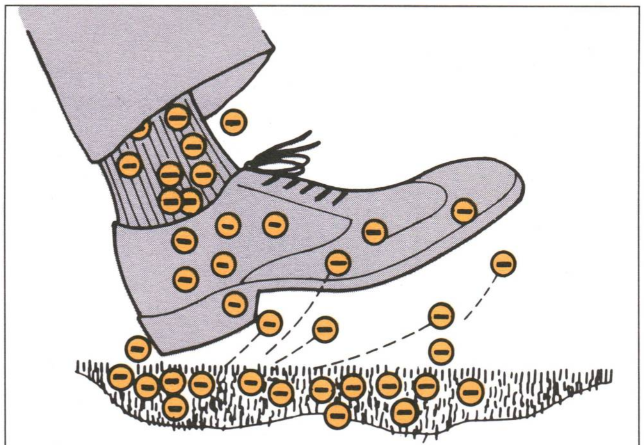
SOURCES OF ELECTRICITY

STATIC ELECTRICITY

Static electricity is a condition where an electric charge is temporarily contained in a body that has an excess of electrons. This excess of electrons results from the movement of electrons from one body to another by friction. If you walk across certain dry carpets, electrons move through your shoes. You may then get a ZAP when you touch a lamp or light switch, as the charge is then discharged.

Lightning is another familiar form of static electricity discharging from the atmosphere to earth.

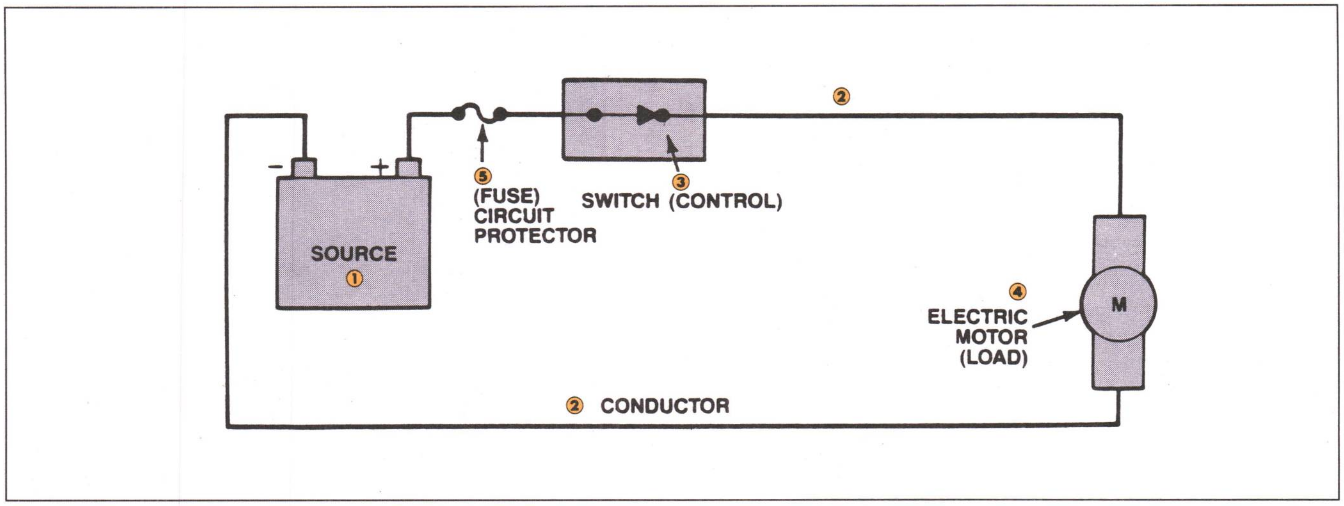
Static electricity has no practical automotive application; it is a nuisance that sometimes must be overcome in design of various kinds of equipment.



FREE ELECTRONS ARE ABSORBED THROUGH SHOES

STATIC ELECTRICITY

ELECTRICAL CIRCUITS



BASIC ELECTRICAL CIRCUIT

An electrical **circuit** is a complete path provided for current flow... from a power source, to a **load** component that contains resistance and uses electricity to do work, and back to the source. It is also called a **closed circuit**, since it must be uniterrupted from and back trrerent current source in order to work.
For electricity to flow, two conditions must be met:

1. The CIRCUIT must be closed. If the switch is open or there is a break anywhere in circuit **continuity**, the circuit will not work.
2. A CHARGE must be available. The power source must have or be producing a charge. Batteries "hold" charges; alternators "produce" charges.

Circuits are usually shown, as in the diagram, **schematically**; that is, as a diagram with lines to represent conductors and symbols to represent components.

COMPONENTS

The components of any electrical circuit are:

① POWER SOURCE. In the automobile, the power source is the **battery** when the engine is off, and usually the **alternator** when the engine is running.

② CONDUCTORS. Wires and cables, usually wrapped in **insulation**, carry the electric current between the load and source. In an automotive circuit, **ground**, the metal part of the chassis, is a conductor in part of the circuit.

③ CONTROLS. The circuit must have a **switch** to control it. The switch opens (off) and closes (on) the circuit. Other controls may be used to regulate the current flow in some way. Switches can be operated mechanically, electrically, or by vacuum.

④ LOAD. The load is a device that uses up electricity and converts it to work. Examples are light bulbs, electric motors, horns, heater coils.

⑤ CIRCUIT PROTECTOR. Most circuits have a **fuse** or some other protective device to break the circuit in case of an electrical overload.

Insulators

Any material with a very high resistance to current flow is called an **insulator** or non-conductor. Typical materials used for insulation are glass, mica, bakelite, rubber (synthetic and natural), porcelain, various fibers, and synthetic materials (plastics).

Insulators or insulation are needed on the "hot" side of the circuit to isolate the wires and terminals from ground.

Conductors

Most automotive wires and cables are made of copper, with synthetic material molded around them for insulation.

Wires and cables connected to the chassis ground usually are insulated also, but would not cause problems if they were bare.

The chassis ground conducts electricity through its iron, steel, and aluminum parts.

ELECTRICAL CIRCUITS

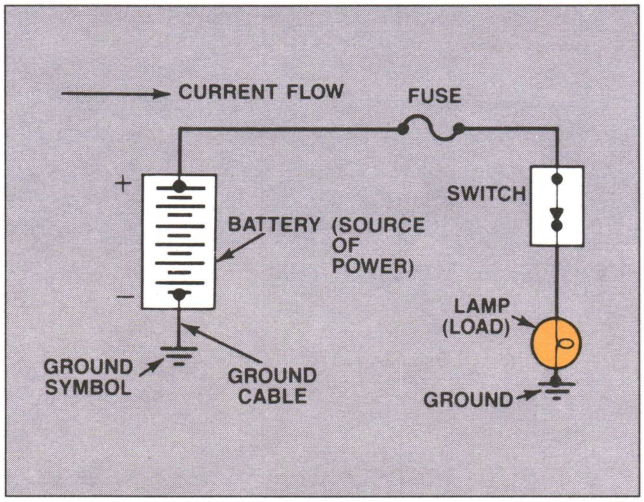
COMPLETE CLOSED PATH

An electrical circuit must provide a complete closed path for the current to flow:

- from the power source, to
- the electrical **load** (the device that uses power and does the work), and
- back to the source.

Even though the load "uses up" the power, the circuit won't work unless it is a complete closed path.

Remember that the circuit is traced in the opposite direction of the current flow.



COMPLETE CIRCUIT

SINGLE-WIRE CHASSIS GROUND

In the automobile, wire is used principally on the hot (positive) side of the circuit. The **ground** side is principally the chassis metal. Thus, automotive circuits are generally classified a **"single-wire,"** referring to the hot side.

Of course, there are some wires in the ground side of the circuit.

- The battery ground cable consists of many strands of wire.
- Many components have ground wires to connect the ground side of the load to the chassis ground.

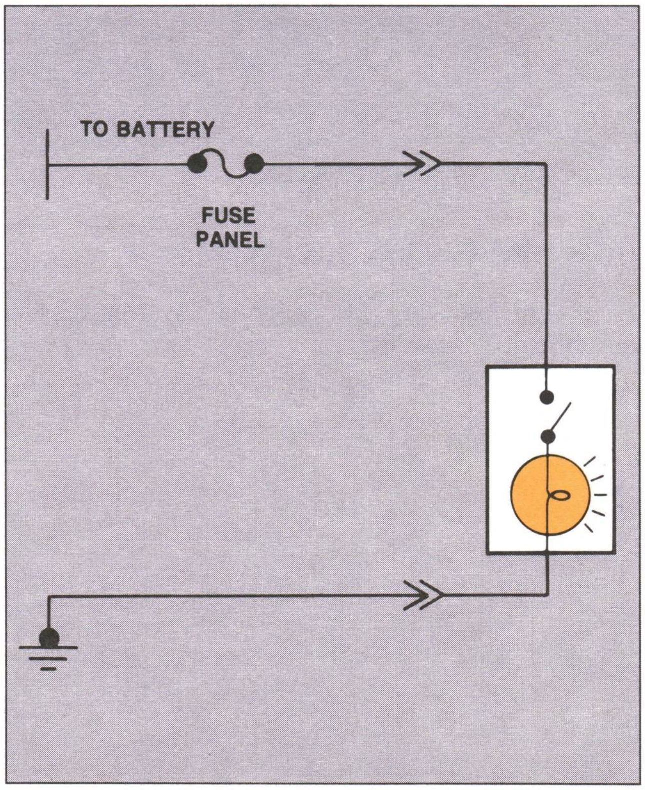
SELF-GROUNDED COMPONENTS

The lamp shown in the previous illustration has the ground symbol on the lamp symbol to indicate that the lamp socket is self-grounded by direct attachment to a metal part. Notice how it differs from the battery ground symbol, indicating that the battery is grounded away from its case.

TWO-WIRE CIRCUITS

Most non-automotive circuits, for example house wiring, are called **two-wire circuits**, because they use a second wire instead of a chassis ground for the "return" side of the circuit.

In the automobile, the power window control resembles a two-wire circuit. It has two wires from the motor to the switch. These alternate as hot and ground, since the motor is reversible. However, there is still a chassis ground, so it is not a pure "two-wire circuit."

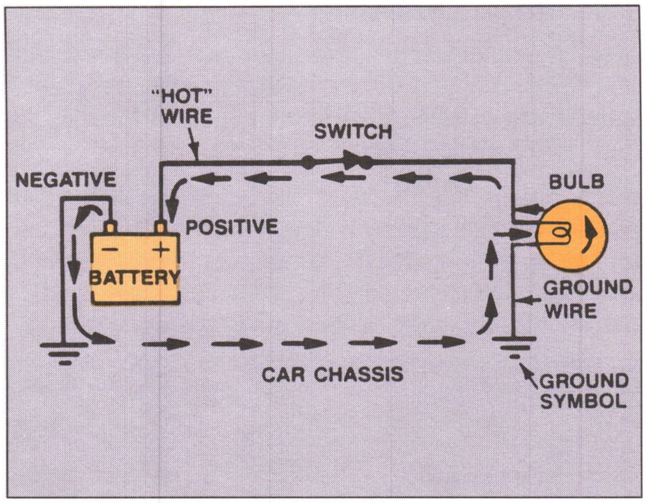


TWO-WIRE CIRCUIT

NEGATIVE GROUND SYSTEMS

Ford automotive systems have the battery connected with the negative terminal to ground. The positive terminal is connected to a main power terminal, usually located for convenience on the starter relay. The positive **leads** or **hot wires** all are connected to the positive side of the battery.

When a switch is closed, current flows from the battery negative post to the chassis ground, through the load and switch, and to the positive terminal. Even though ground has the excess of electrons, the positive side of the battery tests "hot" in negative-ground systems.



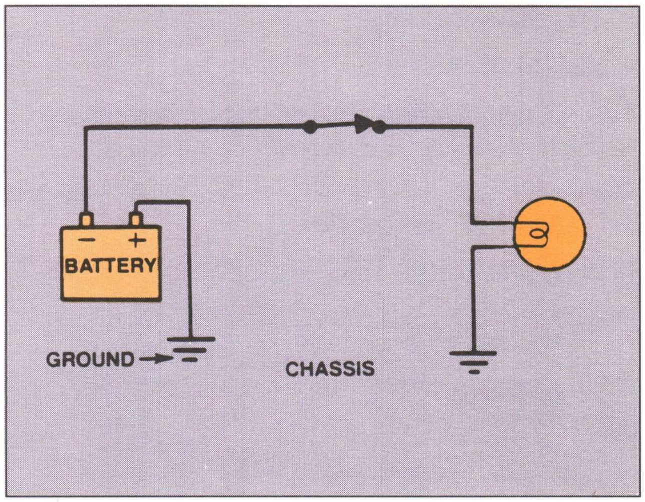
NEGATIVE GROUND SYSTEM

POSITIVE-GROUND SYSTEMS

Some vehicles have a positive-ground system, the battery polarity is reversed.

On these vehicles, current flows from the negative terminal, through the switch and load, to ground, and to the positive terminal.

In a positive-ground system, the "hot" or "lead" wires are all connected to the negative side.



POSITIVE GROUND SYSTEM

BASIC CIRCUIT ARRANGEMENTS

Electricity moves through an automotive system by means of a **complete** or **closed circuit.** This basic circuit is a complete path from a power source to the component and back.

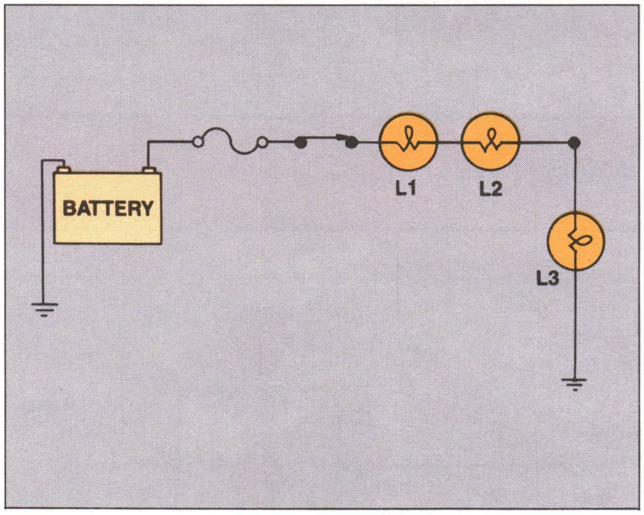
Circuits can be arranged in three ways:

1. **Series**
2. **Parallel**
3. **Series-parallel**

SERIES CIRCUIT

In a **series circuit**, the components, or loads, are arranged so the current passes through each load and returns to the power source through the ground circuit.

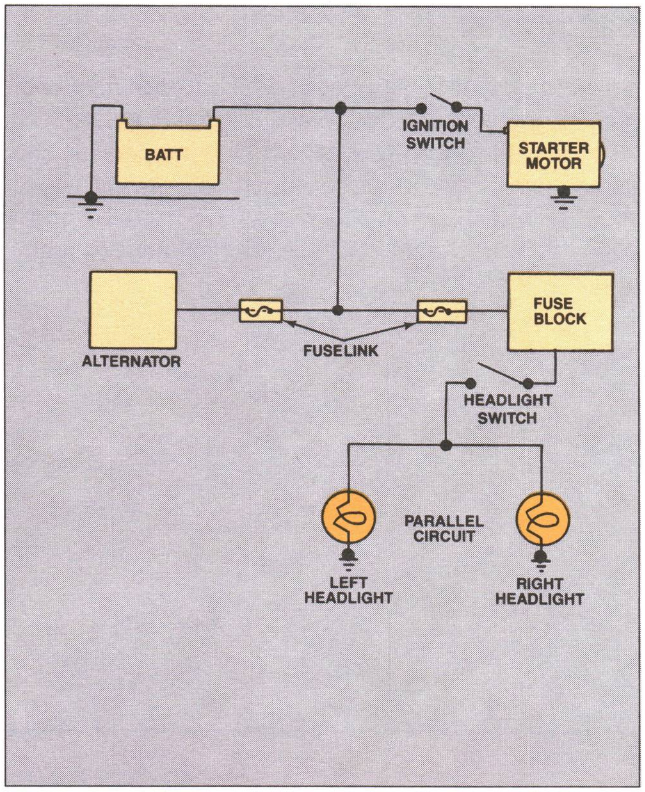
Since there is only one path of current flow in a series circuit, an open anywhere in the circuit will cause all loads to stop working.



SERIES CIRCUIT

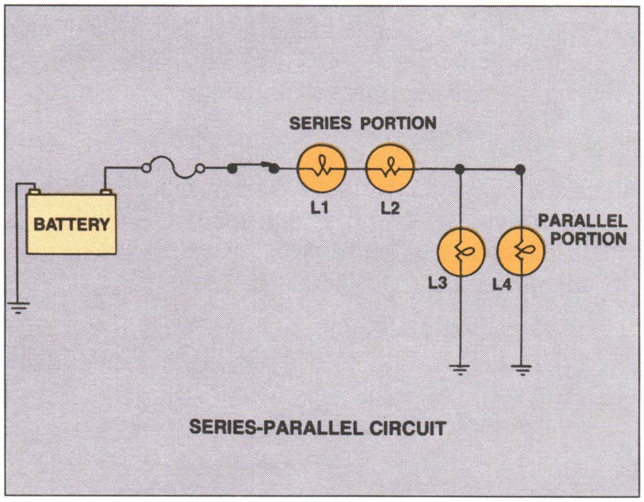
PARALLEL CIRCUIT

Loads in a **parallel circuit** are arranged with individual paths of current flow.



PARALLEL CIRCUIT

When a splice divides the current into two or more branches, each branch is a complete circuit from power to ground. Because of this arrangement, if one circuit is opened, the other will continue to operate.



SERIES-PARALLEL CIRCUIT

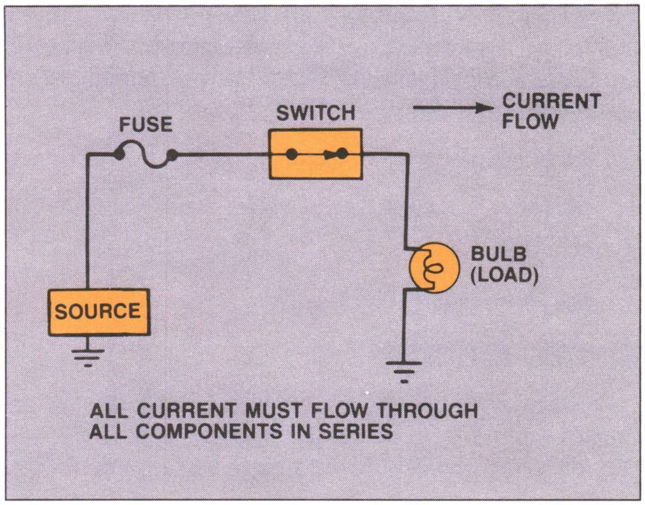
SERIES-PARALLEL

A **series-parallel circuit** combines elements of a series circuit and a parallel circuit.

SERIES CIRCUIT

DEFINITION

A **series circuit** is a circuit in which its separate components are connected successively end to end to form a single path for the current to flow. Components connected in this fashion are referred to as being "in series." That is a condition where two or more components are connected one after another, or within a single loop.



SERIES CIRCUIT

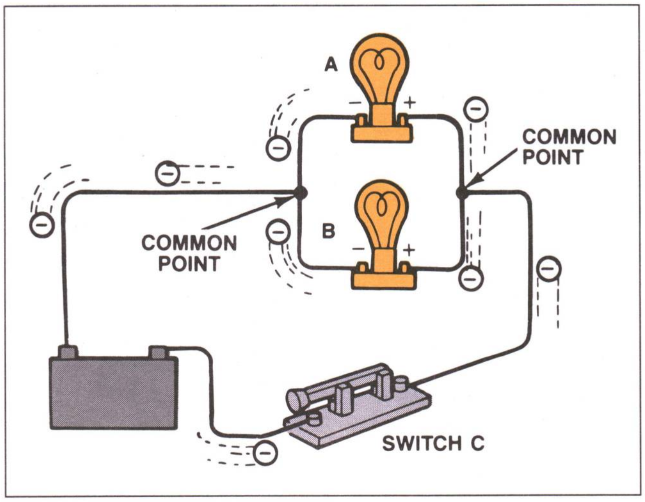
PARALLEL CIRCUIT

DEFINITION

A **parallel circuit** is one in which two or more loads are connected side by side and are controlled by the same switch, but operate independently of each other. This arrangement provides full electrical potential (voltage) to all portions of the circuit.

In a parallel circuit:

1. Each of the loads draws current independently of the other. If A and B are equivalent bulbs, the combination will use twice as much power as a single bulb.
2. If the parallel branch for one load is open, it doesn't affect the other. If you open branch B by removing the bulb, bulb A will still glow as long as the switch is closed.

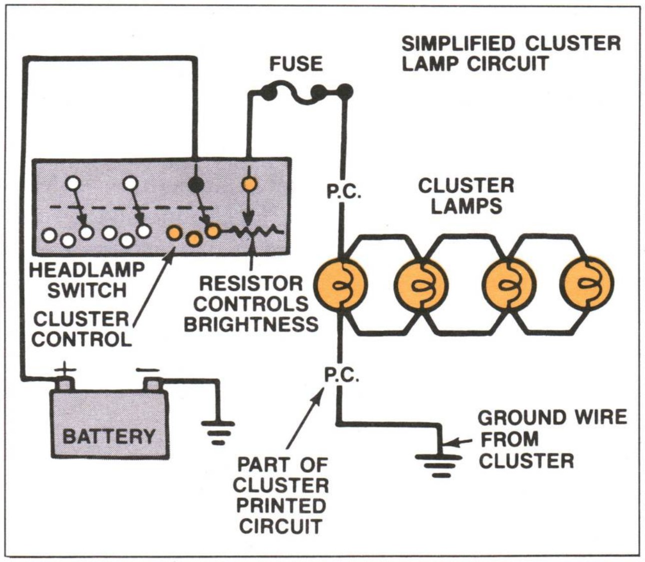


PARALLEL CIRCUIT

SERIES-PARALLEL CIRCUIT

DEFINITION

A **series-parallel circuit** is a combination of series and parallel. It has two or more loads in parallel, plus an additional load or loads in series.


SIMPLIFIED CLUSTER LAMP CIRCUIT
FUSE
P.C.
CLUSTER LAMPS
HEADLAMP SWITCH
CLUSTER CONTROL
RESISTOR CONTROLS BRIGHTNESS
P.C.
BATTERY
+
−
PART OF CLUSTER PRINTED CIRCUIT
GROUND WIRE FROM CLUSTER

SERIES-PARALLEL CIRCUIT

RESISTANCE

DEFINITION

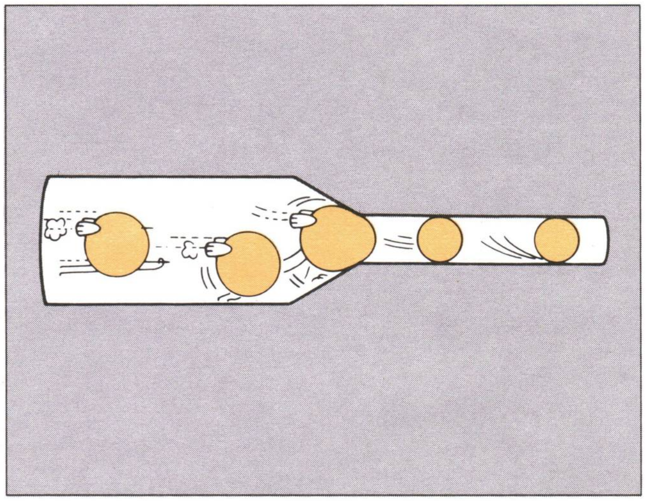
Resistance is the opposition to current flow created by a load, or other part of the circuit.

The practical unit for measuring electrical resistance is the **ohm**. Thus one ohm is defined as the amount of resistance that will allow one ampere of current to flow with an EMF of one volt.

Even conductors have some resistance. For example 60 feet of copper wire has a resistance of one ohm. Wire resistance increases proportionally to length, but decreases proportionally to cross section area.

Heat usually causes resistance to increase. In a few materials, such as carbon, the resistance decreases with heat. Usually the increase or decrease is not important.

Corrosion on terminals and loose connections causes resistance to increase in a circuit. The result is reduced current draw.



RESISTANCE

CURRENT

DEFINITION

Current is the flow of electrons from a negative to a positive charge, or between two points in a closed circuit that have a difference in potential.

The unit of measurement to determine current flow in a circuit is the **ampere** (**amp**). One ampere is defined as the movement of one **coulomb** of electrons past a given point in one second. A coulomb is a quantity of a billion billion electrons.

Current thus is a measure of flow rate. It is also known as amperage or **draw**. Draw refers to the amount of current a given resistance will pull or conduct with a given voltage. Draw is high with a low resistance and low with a high resistance.

Current is measured with an ammeter.

VOLTAGE

DEFINITION

Voltage is the push or pull exerted by electrical charges. Its technical name is **electromotive force** (EMF), which literally means "a force that moves electrons." The unit of measure is the volt, the more common name for voltage. The **voltmeter** is an electric meter used to measure EMF.

Battery Voltage

Battery voltage is the voltage measured between the two terminals of a battery. A strong or fully charged battery in a modern car measures just above 12 volts.

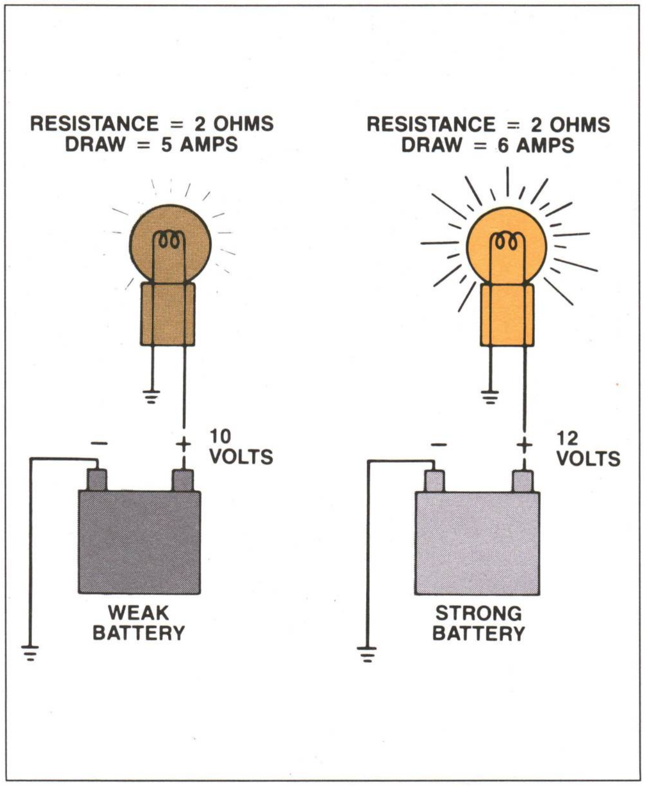
Charging Voltage

Charging voltage is the measured voltage of the alternator output.

- Increasing voltage, with a given resistance, always increases current draw. For example, a bulb burns brighter with a strong battery than with a weak one.

Available Voltage

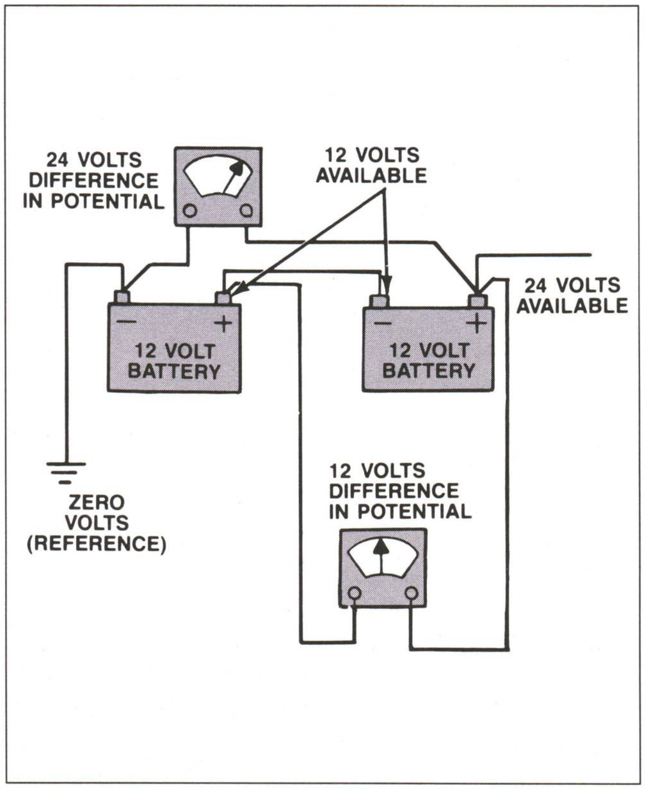
Available voltage is the measured voltage at the source or other point in the circuit with respect to ground. Ground is always taken as a reference point of zero voltage. No-load voltage is voltage anywhere in the hot circuit with the switch open. It equals source voltage.



AVAILABLE VOLTAGE

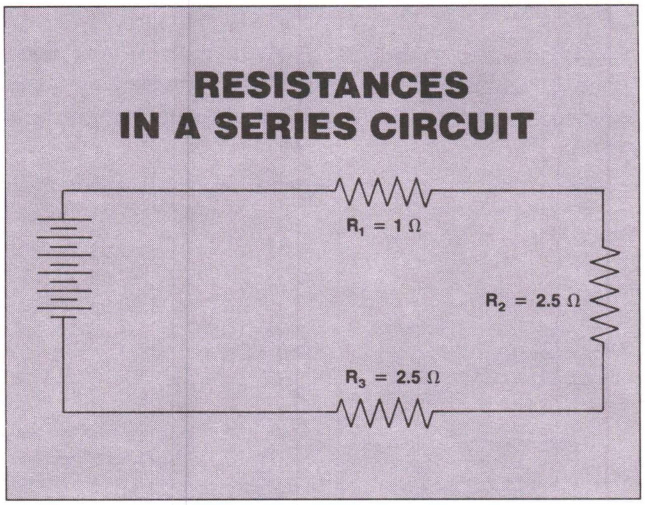
DIFFERENCE IN POTENTIAL

Voltage is also expressed as **difference in potential** when it refers to electromotive force caused by a difference in electrical charges between two points in a circuit.



DIFFERENCE IN POTENTIAL

RESISTANCE IN A SERIES CIRCUIT



SERIES CIRCUIT RESISTANCE

Resistance is the opposition to current flow caused by a load or other parts of the circuit. Since resistances in a series circuit are additive, the total resistance is the sum of all the resistances added together.

For instance, one ohm plus two-point-five ohms plus two-point-five ohms equals a total resistance of six ohms.

CURRENT IN A SERIES CIRCUIT

Since the current load is the same through every load and every conductor in a series circuit, and depends on the combined resistance of the circuit, the total is determined by:

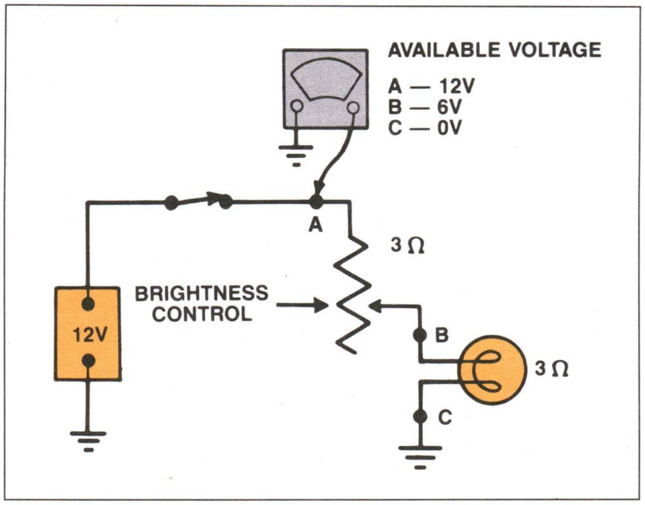
$$V/R = A$$

The volts, divided by the resistance, equals the total amps. Or, in this example:

$$12 \text{ VOLTS} \div 6.0 \text{ OHMS} = 2.0 \text{ AMPS}$$

Twelve volts divided by six ohms of resistance equals two amps. This is a perfect example of the application of Ohm's Law.

VOLTAGE IN A SERIES CIRCUIT

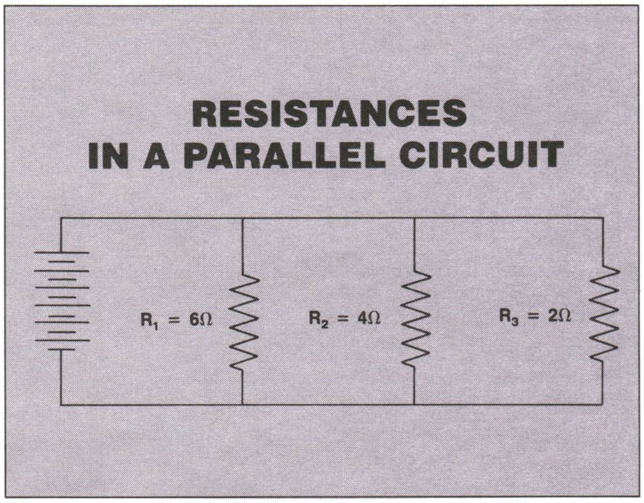


SERIES CIRCUIT VOLTAGE

Voltage in a series circuit will drop as the current flows through more loads in the circuit because the resistance is greater.

Voltage drop testing is often used in circuit diagnosis to locate points of high resistance.

RESISTANCE IN A PARALLEL CIRCUIT



PARALLEL CIRCUIT RESISTANCE

To figure total resistance in a parallel circuit, begin with the voltage. It will probably be 12, but any number that fits can be used. Then divide that number by each resistor. In this example:

12 VOLTS ÷ 6 OHMS = 2 AMPS

12 VOLTS ÷ 4 OHMS = 3 AMPS

12 VOLTS ÷ 2 OHMS = 6 AMPS

Twelve volts divided by six ohms equals two amps. Twelve volts divided by four ohms equals three amps. And twelve volts divided by two ohms equals six amps.

2 AMPS + 3 AMPS + 6 AMPS = 11 AMPS.

Then add the two amps, three amps, and six amps, and get a total of eleven amps.

12 VOLTS ÷ 11 AMPS = 1.09 OHMS

Finally, divide the twelve volts by the eleven amps and get one-point-zero-nine ohms, which is the total resistance in the parallel circuit.

CURRENT IN A PARALLEL CIRCUIT

The total current flow in a parallel circuit equals the sum of the individual current draws. Using the previous examples, it works like this:

VOLTAGE = 12 VOLTS

TOTAL RESISTANCE = 1.09 OHMS

VOLTAGE ÷ OHMS = AMPS

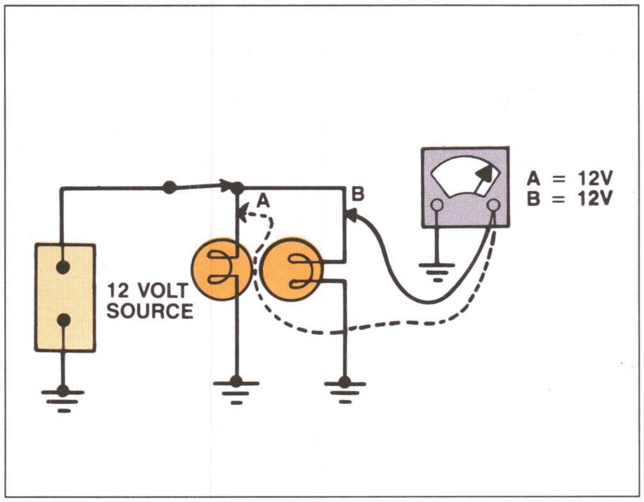
12 VOLTS ÷ 1.09 OHMS = 11.0 AMPS

The voltage was 12. The total resistance in the circuit was one-point-zero-nine ohms.

The voltage is divided by the ohms to get the amps or current flow.

That's 12 volts divided by one-point-zero-nine ohms which gives 11 amps of current in the circuit.

VOLTAGE IN A PARALLEL CIRCUIT



PARALLEL CIRCUIT VOLTAGE

Voltage into each branch in a parallel circuit is equal to the source voltage.

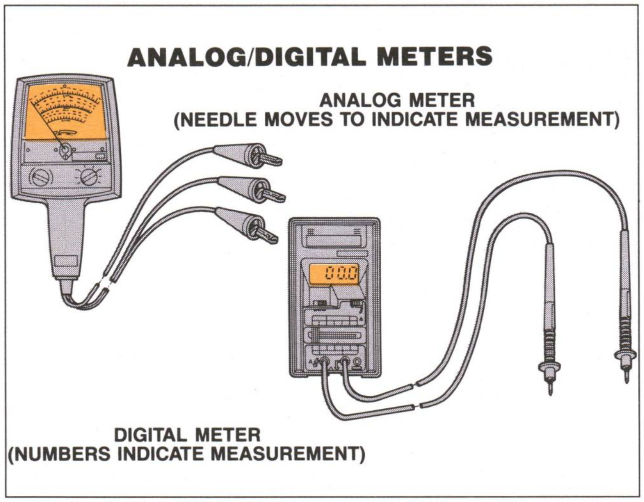
In this example, each branch in the circuit would read 12 volts on a voltmeter because that is the source voltage.

ELECTRICAL MEASURING DEVICES

There are many types of electrical measurement devices. The correct use of the correct measurement device is vital for accurate diagnosis and testing.

One of the most commonly used measurement devices is the multimeter. There are two basic types:

- **the analog meter**
- **the digital meter**


ANALOG/DIGITAL METERS

ANALOG METER
(NEEDLE MOVES TO INDICATE MEASUREMENT)
0.0.0
DIGITAL METER
(NUMBERS INDICATE MEASUREMENT)

MULTI-METERS

ANALOG METERS

Analog meters indicate measurement by a spring loaded needle that moves across a calibrated scale. The value displayed must be visually interpreted, so the analog meters are not as accurate as digital meters.

DIGITAL METERS

Digital meters are electronic and display the value of the measurement in numbers on the face of the meter.

They are more accurate than analog meters because the readings are displayed to a fraction of a unit. Interpretation of the readings is unnecessary, so there is less chance of error.

TEST EQUIPMENT CAUTION

When testing electronic components, always use a meter with high internal resistance between the test lead connections – or, to put it another way, a meter with high input impedance – such as a digital meter.

A typical **analog meter** has an input impedance between 25 and 50 thousand ohms.

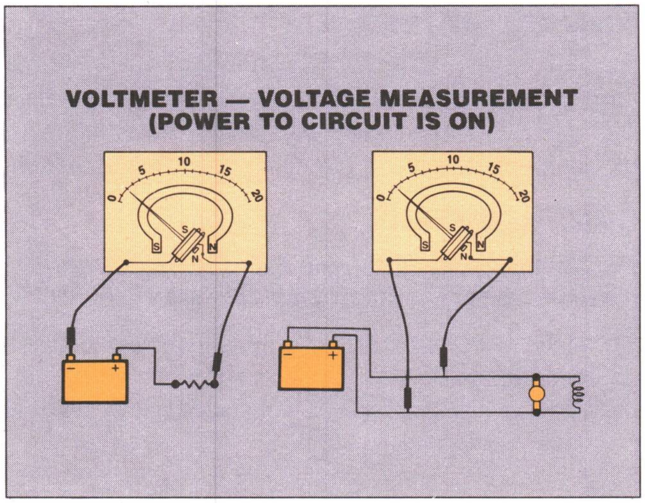
A meter with very low resistance allows too much current load through the meter and could overload the capacity of the circuit and burn it out.

A typical **digital meter** has a much higher input impedance of 10 meg or more per volt and won't allow too much current flow through the meter.

Always use the digital meter to test electronics if special leads for the analog meter are not available.

The voltmeter function is used most often, either to read available voltage in a circuit or to detect voltage drop between any two points in a circuit.

CORRECT METER USAGE



TESTING FOR VOLTAGE

STEP ONE

The first step in using any meter is to select the correct scale for the application.

STEP TWO

The second step is to take a voltage reading. Turn on the power to the circuit and connect the meter leads across the component being measured.

Remember, when using an analog meter, observe polarity when connecting the positive and negative leads.

Digital meters aren't polarity sensitive. If the leads aren't connected right, a minus sign will appear in front of the reading.

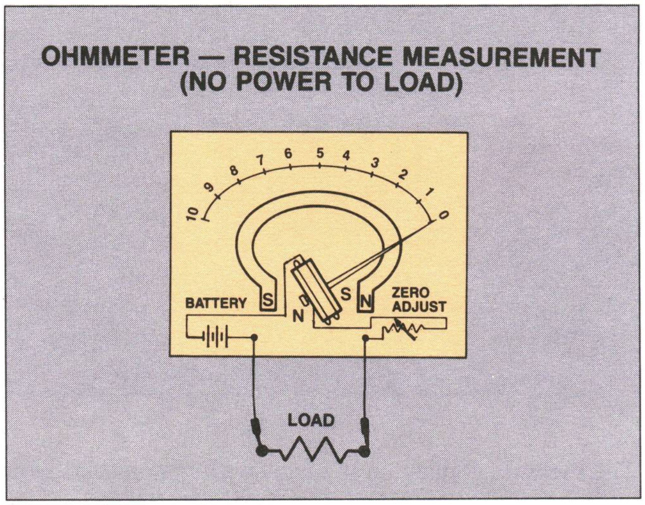
STEP THREE

The last step in the voltage test is to read the scale to which the meter is set.

If the readout is plus-one on a digital meter, or if the needle is off the scale on an analog meter, the meter must be set up one scale to get an accurate reading.

THE OHMMETER FUNCTION

Resistance in a circuit is tested with the ohmmeter function. Begin by setting the meter to the correct scale.



OHMMETER — RESISTANCE MEASUREMENT (NO POWER TO LOAD)

MEASURING RESISTANCE

ANALOG METER

An analog meter must be set to zero to make sure it gives an accurate reading.

If the meter is reading accurately, the needle will align with the zero mark on the ohm scale when the leads are touched together.

If that doesn't happen, use the "zero set" knob to align the needle with the zero point on the scale.

DIGITAL METER

If a digital meter gives a reading other than zero when the leads are touched together, that indicates that the battery is low.

If that happens, write the number down, and then subtract it from all resistance readings taken until the battery can be replaced.

CAUTION

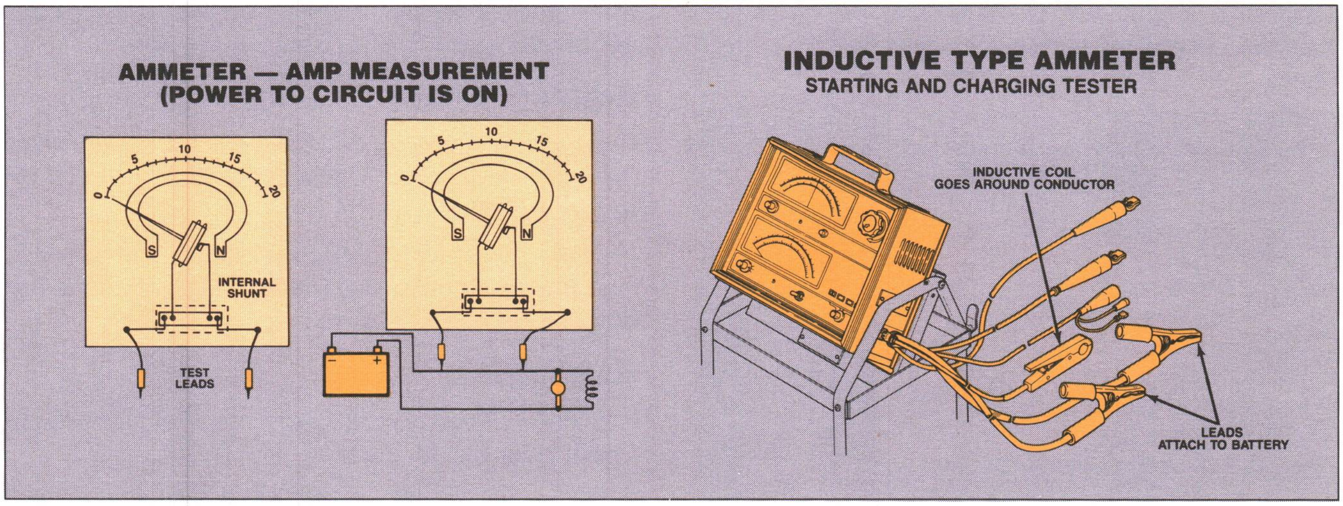
Never connect an ohmmeter to a "live" circuit because it will burn out the meter.

Also, be sure that the component being tested is isolated from other components in the circuit.

Resistance is measured by connecting the leads connected across the component. The meter sends a small amount of current through the component being tested to find the resistance.

Then the results can be read off the scale.

THE AMMETER FUNCTION



TWO TYPES OF AMMETERS

Current in a circuit is measured with the ammeter function.

There are two basic types of ammeter used, depending on the amount of current being tested.

INTERNAL SHUNT AMMETER

The internal shunt ammeter gives very accurate readings on circuits of ten amps or less.

To take a reading with a shunt ammeter, set it to the correct scale and turn the power to the circuit ON with the primary ignition disabled. This allows the amount of current that flows through the meter to be measured.

The meter is connected in series with the circuit that is being tested, never across the circuit. The meter or current could burn because of too much current flow.

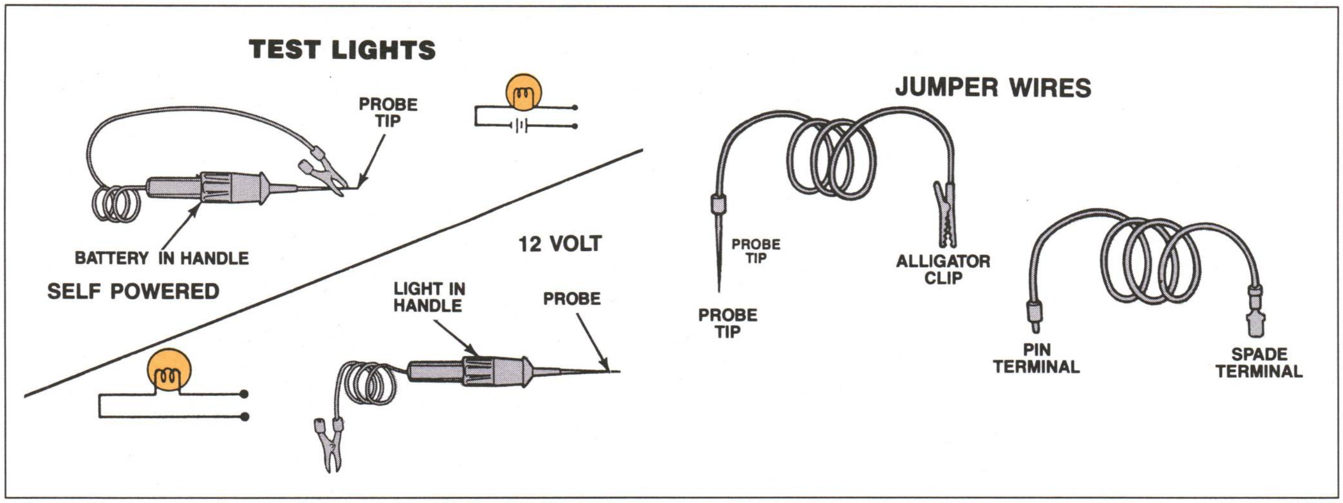
INDUCTIVE TYPE AMMETER

The inductive type ammeter is used to read current flow in circuits over ten amps. This type of meter will not give a precise reading below ten amps.

To take a reading with an inductive ammeter, two leads are connected to the vehicle battery. A third lead with a clamp is connected to the conductor being tested.

If the coil is hooked up in the wrong direction, the meter will show charge instead of discharge, or vice versa.

ALTERNATIVE TESTING DEVICES



CONTINUITY TESTERS AND JUMPER WIRES

Some other handy testing devices are:

- **the continuity tester**
- **the testlight**
- **jumper wires**

Each one has its own application.

CONTINUITY TESTER

A continuity tester, or self-powered test light, will indicate whether a current path is complete; that is, if there is continuity in the circuit.

When the tester is connected in series with the power to the circuit OFF, the lamp in the handle will glow if the circuit has continuity.

This is a quick check and shouldn't be used in place of an ohmmeter.

TEST LIGHT

A quick test for the presence of voltage, but not the amount of voltage, can be done with a 12-volt test light.

With the power ON, one end of the tester is connected to a ground, and the other end is touched to the wire being tested. If there is voltage in the wire, the lamp in the tester will glow. To test for the actual amount of voltage, a voltmeter must be used.

JUMPER WIRES

Sometimes jumper wires are used to help diagnose continuity across components which might be open, or they can be used to supply battery voltage to a circuit, independent of normal switches or wiring.

A jumper wire can be equipped with the same type of probe and clips as a continuity tester or with specialized connectors and terminals for specialized testing.

In either case, check jumper wires with an ohmmeter periodically to make sure theres no resistance in the connections.

POWER SOURCES AND GROUNDS

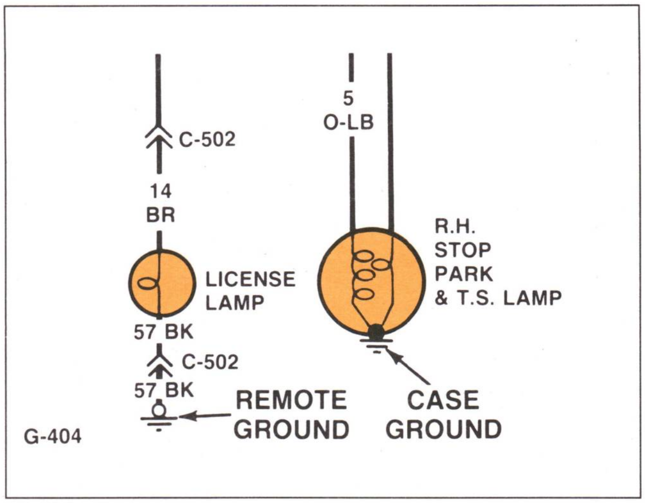
STORAGE BATTERY AND ALTERNATOR

The storage battery provides electrical power for starting the vehicle and provides current to all electrical systems during key-on, engine-off modes. After the engine is started, the alternator maintains the charge in the battery and supplies electrical current to all electrically powered equipment in the vehicle.

GROUNDS

Case grounds are used where the component is securely attached to a well-grounded part of the vehicle, and the component has a metal case.

Remote grounds are used where the component itself is not grounded, or where remote ground is used to control the component (for example, reversible motors, some instrument panel warning lights).



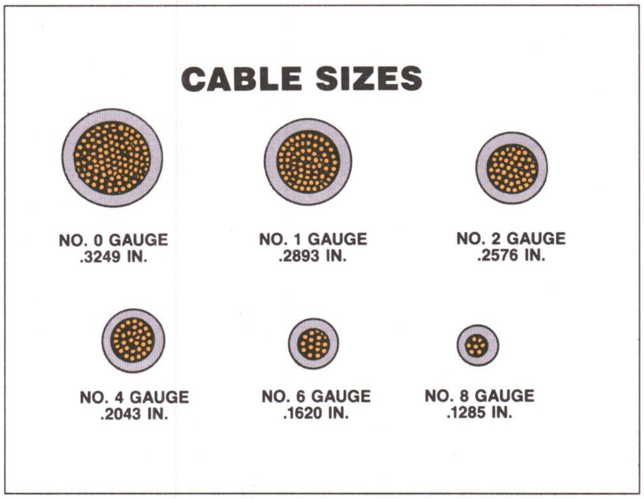
GROUND SYMBOLS

ELECTRICAL COMPONENTS

CONDUCTORS

Conductors, which are commonly called wires, carry current to and from the components in a circuit.

Generally, they're made of copper with a non-conductive insulating cover.



CONDUCTORS

Wire Size

The size of the wire used in a circuit depends on the amount of current it carries. Wire sizes from zero gauge to 20 gauge are used in automotive electronics. The higher the gauge, the smaller the wire.

Wiring Harness

The point where a number of wires from a group of components meet is called a wiring harness or, sometimes, a wiring loom. Generally, a harness will connect components in one area of the vehicle to another.

CIRCUIT PROTECTION DEVICES

Circuit protection devices are used to avoid damage to a circuit due to excessive current flow. They include:

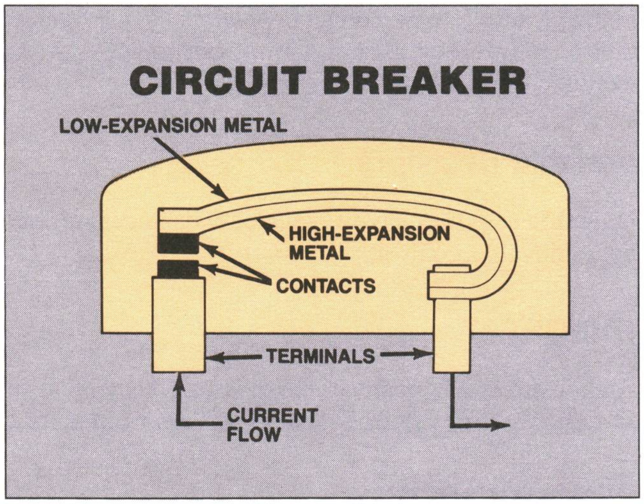
- **fuses**
- **fuse blocks**
- **circuit breakers**
- **fuse links**
- **thermal limiters**

FUSE

The conductive element of a **fuse** allows current to flow within the rating for the circuit, but excessive current causes it to melt and open the circuit.

FUSE BLOCK

The fuse block is usually located under the instrument panel and holds the fuses and supplies power to a number of circuits.



CIRCUIT BREAKER

CIRCUIT BREAKER

When power has to be restored to a blown circuit in a hurry, a **circuit breaker** is used. Most often, cycling circuit breakers are used in automotive applications.

When heat builds up because of excessive current flow, the bi-metal strip bends up and breaks the contact. The circuit is open and no current flows.

When the bi-metal strip cools, it bends down again and closes the circuit so current will flow.

NON-RECYCLING CIRCUIT BREAKER

In circuits that are powered even when the ignition is off, such as power seats and door locks, a **non-recycling circuit breaker** is used.

A wire coil wrapped around the bi-metal strip holds the excessive heat that caused the circuit to break. Because of this, the circuit won't close until the power has been removed. Then the bi-metal strip cools and the circuit is closed again.

FUSE LINK

A **fuse link** is installed close to the power source to protect large portions of the vehicle wiring where fuses and circuit breakers wouldn't be practical.

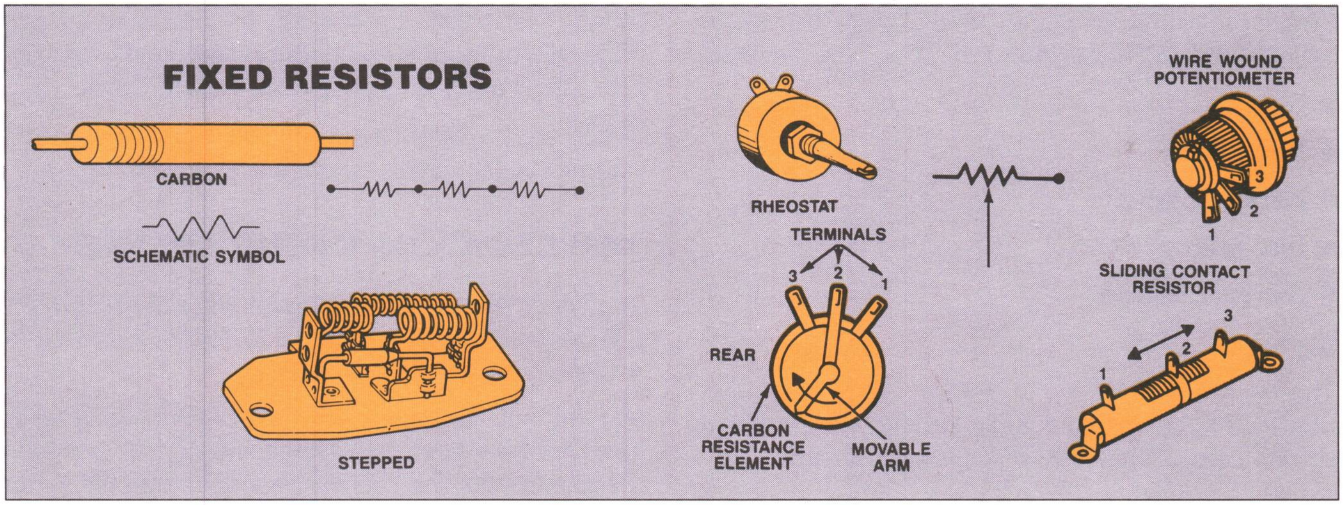
The link is normally made of a copper alloy four gauge sizes smaller than the circuit wire. If the circuit overheats, the lighter wire will melt and open the circuit. The heat-resistant, non-flammable insulation bubbles when the link melts and indicates that it's open and has to be replaced.

THERMAL LIMITER

In a system where current flow isn't a good indicator of a problem, a thermal limiter is installed. The limiter is sensitive to excessive heat in the components around it. At a specific temperature, the limiter disables the circuit.

Ford uses thermal limiters in most A/C blower circuits. They partially or completely disable the blower motor if there is not enough air flow in the case to keep the motor resistor cool.

ELECTRICAL CONTROLLING DEVICES



RESISTORS

The main electrical controlling devices used in automotive electronics are used to limit or control the flow of current in circuits. They include:

- **resistors**
- **switches**
- **relays**
- **solenoids**
- **diodes**
- **capacitors**
- **coils**

RESISTORS

Resistors limit current flow in circuits where full flow or voltage isn't needed. They cause a voltage drop and dissipate the power as heat.

Some typical uses of resistors to produce heat are an electric window defroster, a choke cap heater, and a cigarette lighter.

There are three types of resistors:

1. **fixed value**
2. **stepped** or **tapped**
3. **variable**

Fixed Value Resistor

Fixed value resistors have a specific value and are rated in ohms. They can be built into a component or installed in-line.

Step Resistor

Step resistors have two or more fixed values. The value is selected by connecting wires to the various taps on the resistor. Blower motor resistor packs are an example of this type of resistor.

Variable Resistors

Variable resistors have a range of resistances selected by a movable control.

RHEOSTAT

A **rheostat** is a typical variable resistor. They are used in radio volume controls and panel lamp dimmers.

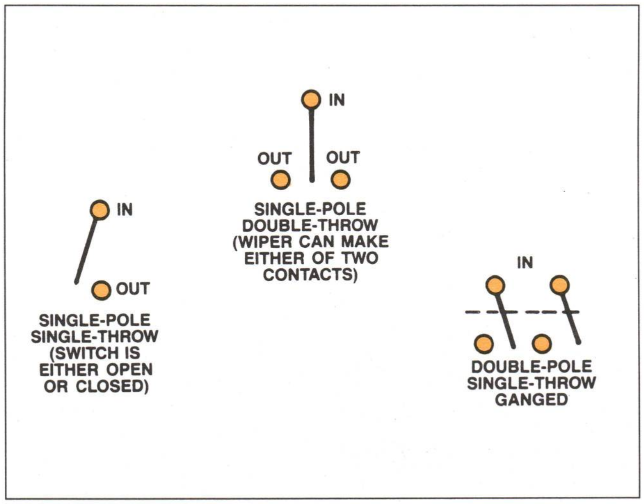
POTENTIOMETER

A **potentiometer** is similar to a rheostat except that instead of just raising and lowering voltage as the control is moved, it can also balance the current flow on either side of the wiper. This makes it useful for applications like balance control for stereos. Or it can function as a voltage divider in a system such as Electronic Engine Controls.

SWITCHES

Switches are on-off controls that can either open or close a circuit. They can be manual or self-operating and either normally open or normally closed.

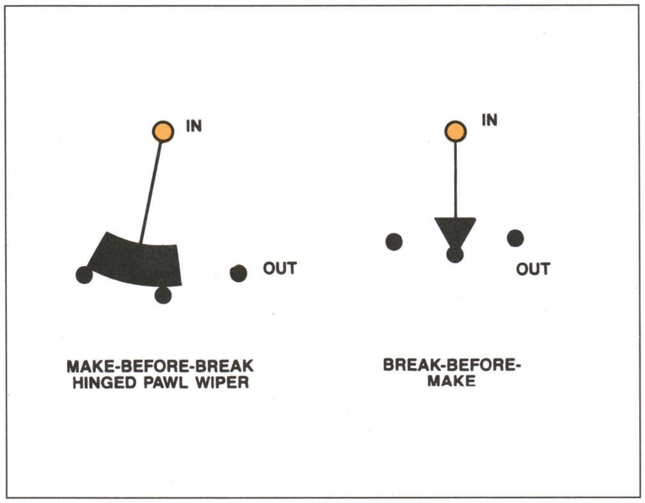
ELECTRICAL CONTROLLING DEVICES


IN
OUT
SINGLE-POLE SINGLE-THROW (SWITCH IS EITHER OPEN OR CLOSED)
IN
OUT
OUT
SINGLE-POLE DOUBLE-THROW (WIPER CAN MAKE EITHER OF TWO CONTACTS)
IN
DOUBLE-POLE SINGLE-THROW GANGED

SWITCHES

Hinged Pawl Switch

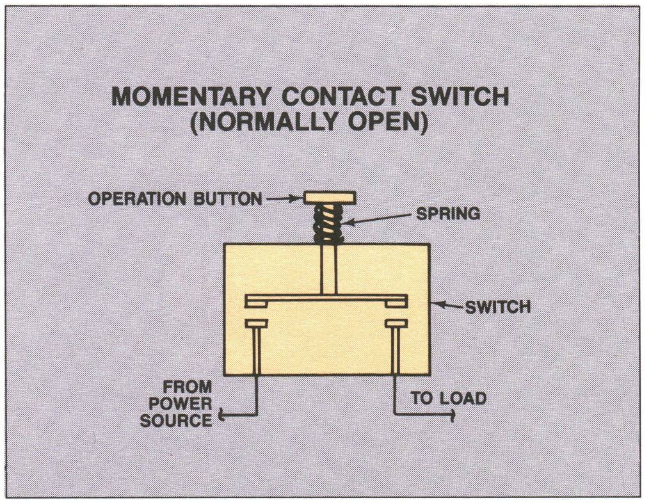
The simplest kind of switch is a **hinged pawl switch.** It either makes or breaks the current in a single conductor or circuit. High and low beam headlamp circuits use hinged pawl switches.



HINGED PAWL SWITCH

Momentary Contact Switch

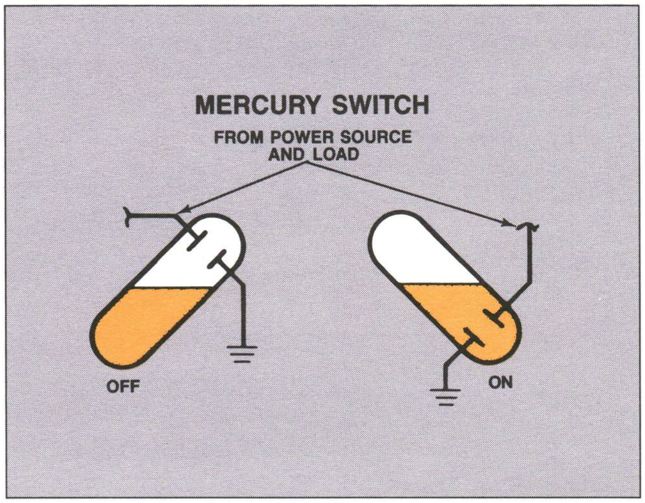
A **momentary contact switch** has a spring loaded contact that keeps it from making the circuit except when pressure is applied to the button. This illustration is a normally open type.



MOMENTARY CONTACT SWITCH

Mercury Switch

A **mercury switch** operates by motion. Both contacts are in one end of a capsule partially filled with mercury. When the switch is tipped, the mercury flows to that end and the current is completed. The light circuit in the engine compartment or trunk is a typical example of this kind of switch.

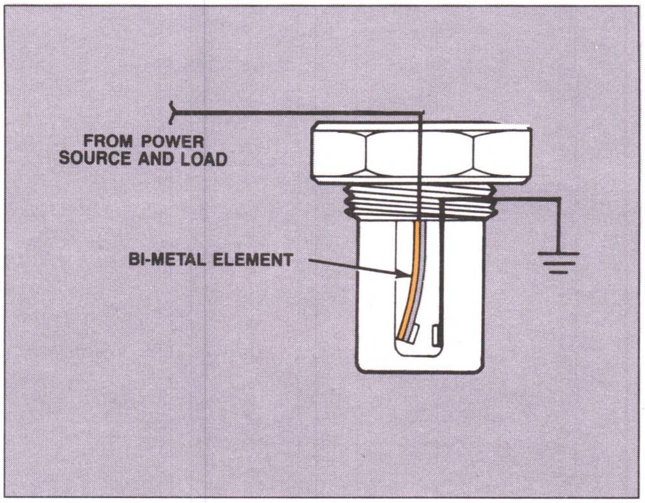


MERCURY SWITCH

Temperature Sensitive Switch

Temperature sensitive switches operate when the bi-metal element is heated and breaks the contact in the circuit. An engine coolant warning indicator is controlled by a temperature sensitive switch.

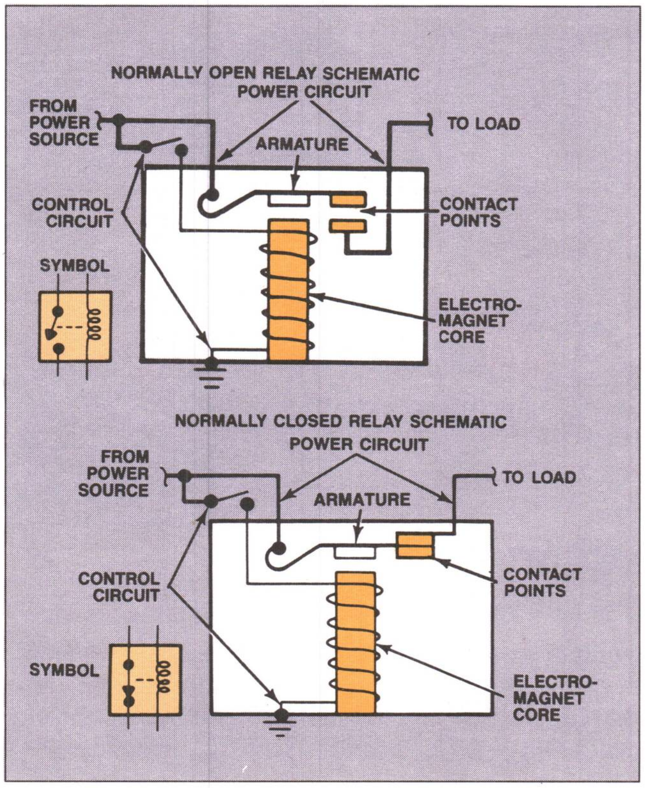
ELECTRICAL CONTROLLING DEVICES



TEMPERATURE SENSITIVE SWITCH

RELAYS AND SOLENOIDS

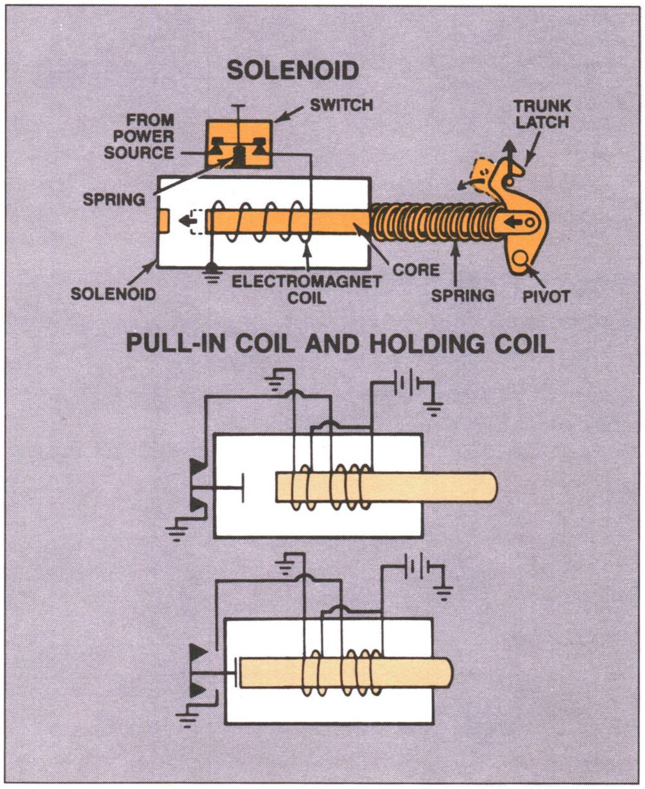
Relays and **solenoids** are also forms of switches, but they contain electromagnets that control current within the circuits.



RELAYS

RELAYS

A **relay** uses a small current flow to control a large current flow. When current is applied to the control circuit, the electromagnet is energized and pulls the armature toward it. That can either open or close the contacts in the switch. Relays are used in the fuel pump, horn, and starter.



SOLENOIDS

SOLENOIDS

Solenoids are electromagnets with movable cores. They're used to change current flow into mechanical movement. They can also close contacts, so they act as a relay at the same time. The A/C compressor clutch and trunk lid release use solenoids.

ELECTRICAL CONTROLLING DEVICES

OTHER CONTROLLING DEVICES

Some other controlling devices are diodes, capacitors, and coils.

Diodes

Diodes allow current to flow in one direction in a circuit and block current from the opposite direction. Logic circuits such as the ignition warning buzzer depend on diodes.

Diodes change the alternating current generated by the alternator to the direct current used by the vehicle electrical system.

Capacitors

Capacitors, also called condensers, absorb or store electrical current. The capacitor is composed of two or more conducting plates separated by a wafer of non-conductive material.

When a capacitor is connected across a voltage source, the voltage draws electrons from one plate and deposits them on the other plate.

When the source voltage is removed from the capacitor, the electrons remain stored on the plate where they were deposited. When the capacitor is connected in series with a complete circuit, the electrons flow back to the depleted plate.

The ability to store electrons makes the capacitor useful in applications where momentary voltage surges occur, such as in the radio feed circuit. Capacitors are also useful in preventing arcing across switch contacts when the switch is opened.

Ignition Coils

An **ignition coil** is a voltage step-up transformer that raises the vehicle voltage to around 50,000 volts so it can jump the spark plug gap.

CHARGING SYSTEM

Because of the amount of electronics used in today's vehicles, the charging system is a critical area.

ALTERNATOR

The **alternator** is the heart of the system when the engine is running.

RECTIFICATION

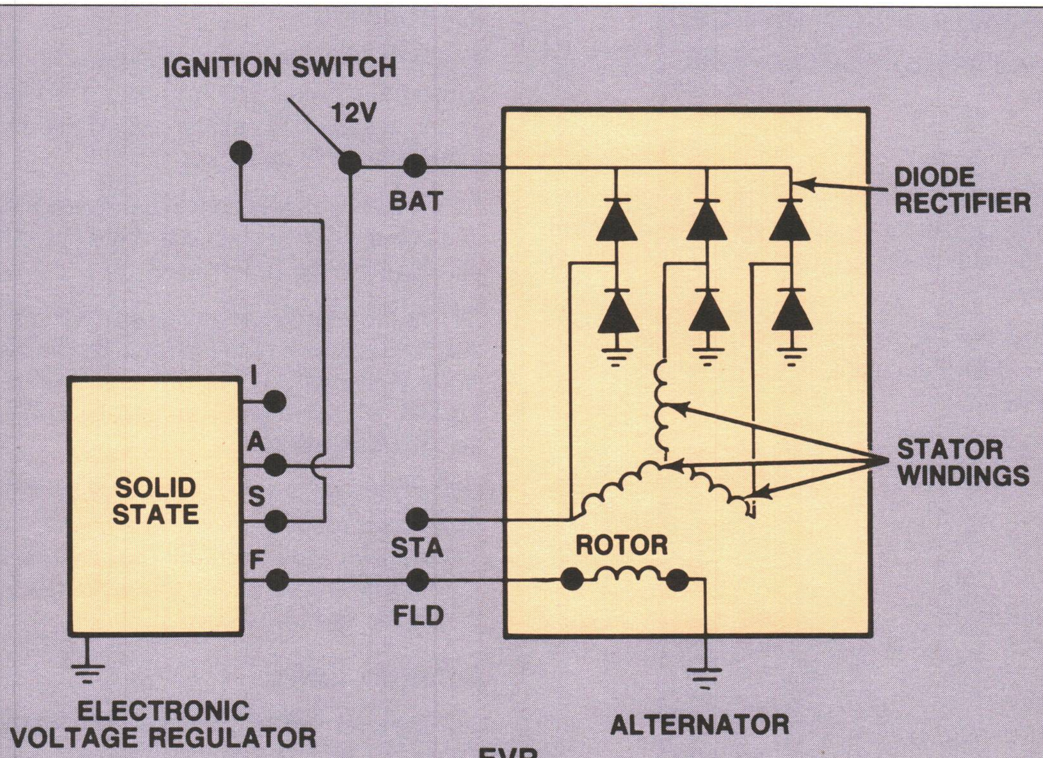
Rectification is necessary because the AC current generated by the alternator must be converted to the DC current that the vehicle electrical system uses.

This is done by semiconductors, or diodes, built into the circuitry of the alternator.

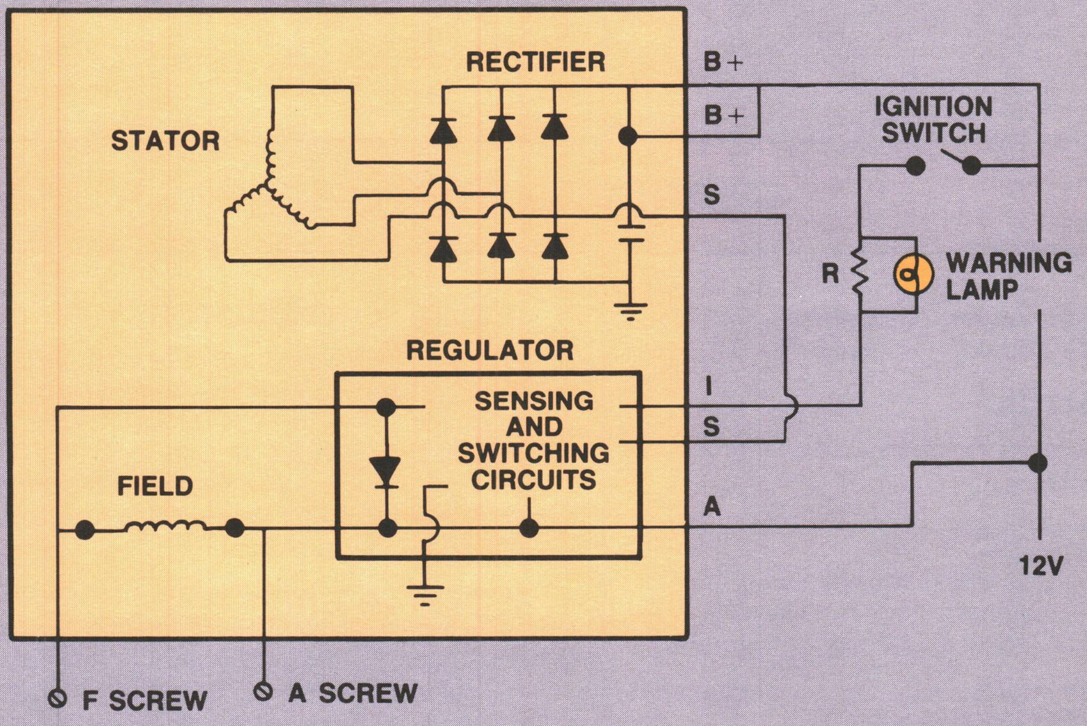
VOLTAGE REGULATOR

The alternator output has to be controlled within prescribed limits. This job is performed by the voltage regulator. The External Voltage Regulator, or EVR, has the voltage regulator mounted on the fender apron of some vehicles. The Integral Alternator/Regulator, or IAR, has a solid state voltage regulator inside the alternator itself.

Basically, the regulator includes a field switch circuit which controls the rotor coil input to the alternator and the electronic control circuit that monitors the stator output to the alternator. The regulator on vehicles that have an ALT indicator light also have an indicator switch circuit to control the light.



EVR



IAR

REGULATORS

AUTOMOTIVE ELECTRONICS: AN OVERVIEW

COMPONENTS

There is a logical and simple reason for the increased use of electronic components in today's vehicles.

Over the years, electrical control and indicator systems replaced the mechanical systems found on early vehicles. These electrical systems were less expensive to produce and easier to install than the, mechanical systems.

Now, electronic systems are replacing the electrical systems because they perform better when they are used to report on or control vehicle components.

BENEFITS

Some of the benefits of using electronic instead of electrical components include:

- **Control**
- **Cost**
- **Reliability**
- **Speed**

Control

An electronic system can give a much larger number of instructions and make decisions based on rules programmed into its memory. One electronic controller can monitor many conditions, analyze the information, and command actions quickly and reliably.

Cost

Electronic systems are very cost effective. The components are relatively inexpensive to produce and replacement costs are low.

Reliability

Solid state technology reduces the number of actual parts in a device. The fewer the parts, the less likely it is that something will wear out.

Speed

Electronic systems gather, analyze, and act on information at incredibly high speed. That means more information can be processed in the same amount of time so the control is better.

GLOSSARY

ALTERNATING CURRENT OR AC:

A flow of current that reverses direction at regular intervals in a conductor.

ALTERNATOR:

A device for converting mechanical energy into electrical energy in the form of alternating current.

AMPERAGE:

Current is also known as amperage or draw.

AMPERE (AMP):

The unit of measurement to determine current flow in a circuit.

ATOM:

An atom is the smallest identifiable particle of a specific element.

AVAILABLE VOLTAGE:

Is the measured voltage at the source or other point in the circuit with respect to ground.

BATTERY:

Two or more storage cells connected together to serve as a DC voltage source.

BATTERY VOLTAGE:

Is the voltage measured between the two terminals of a battery.

CAPACITORS (CONDENSORS):

Are open components composed of two conductor plates with a dielectric between them. Capacitors are used to store electrical current or EMF.

CASE GROUNDS:

Are used where the component is securely attached to a well-grounded part of the vehicle, and the component has a metal case.

CHARGING VOLTAGE:

Is measured voltage of the alternator output.

CIRCUIT BREAKERS:

Is a circuit protection device. Circuit breakers are used in circuits where temporary overloads are common and where power must be rapidly restored.

CIRCUIT OR CLOSED CIRCUIT:

A complete path provided for current flow. It must be uninterrupted from and back to current source in order to work.

CONDUCTOR:

A solid, liquid or gas which offers little opposition to the continuous flow of electric current.

CONTINUITY:

A continuous path for the flow of current in an electric circuit.

COULOMB:

Is a quantity of a billion billion (6.25×10^{18}) electrons.

CURRENT:

The flow of electrons measured in amperes.

DIFFERENCE IN POTENTIAL:

Another way to express voltage when it refers to electromotive force.

DIODES:

Let current flow in one direction in a circuit but block current flow in the opposite direction.

DIRECT CURRENT OR DC:

A steady flow of current moving continuously in one direction along a conductor.

DRAW:

Refers to the amount of current a given resistance will pull or conduct with a given voltage. Draw is high with low resistance and low with a high resistance.

ELECTRICITY:

Is a natural or man-made condition in which there are positive and negative charges capable of causing the movement of electrons from one body of matter to another.

ELECTROMAGNETIC INDUCTION:

When a conductor, connected to a closed circuit, moves through a magnetic field, electric current or voltage is generated.

ELECTROMOTIVE FORCE OR EMF:

The force that causes the electrons to move from one atom to another atom.

ELECTRONS:

Negatively charged particles which revolve around a central core of an atom.

FREE ELECTRONS:

An electron in the outer orbit of an atom and, therefore, not strongly attracted to the nucleus.

FUSE:

A circuit protective device to break the circuit in case of an electrical overload.

FUSE LINKS:

Is a circuit protection device. A fuse link is a short length of wire smaller in gauge than the wire in the protected circuit. The wire is covered with a thick, nonflammable insulation. An overload causes the link to heat and the insulation to blister. If the overload remains, the link will melt, causing an open circuit.

GROUND:

In an automotive circuit, the metal part of the chassis is a conductor in part of the circuit.

HINGED PAWL SWITCH:

It is the simplest type of switch. It either makes or breaks the current in a single conductor or circuit. Single-pole, single-throw switch.

HOT WIRES:

All are connected to the positive side of the battery.

IGNITION COIL:

A voltage step-up transformer that raises the vehicle voltage to upwards of 50,000 volts to jump the spark plug gap.

INSULATOR:

Any material with a very high resistance to current flow. Typical materials used are glass, mica, bakelite, rubber, porcelain, various fibers, and synthetic materials (plastic).

LEAD:

A connecting wire, such as a test lead, or battery lead.

LOAD:

The load is a component of the electrical circuit that converts electricity to some other form of energy.

MAGNETIC FIELD:

A region in space surrounding a magnet or a conductor through which current is flowing.

MERCURY SWITCH:

Is sometimes used to detect motion in a component, such as the one used in the engine compartment or luggage compartment to turn on the compartment light. Inside the switch, a capsule is partially filled with mercury.

MOMENTARY CONTACT SWITCH:

A spring-loaded contact keeps it from making the circuit except when pressure is applied to the button.

NEGATIVE CHARGE:

A condition in a circuit when the element in question retains more than its normal quantity of electrons.

NUCLEUS:

The central part of an atom. It consists of protons and neutrons, has a positive charge, constitutes practically the entire mass of an atom.

OHM:

The practical unit for measuring electrical resistance. It is abbreviated by the Greek letter omega (Ω).

OHM'S LAW:

Is the basic rule for the relationship between voltage, current and resistance. Current flow is directly proportional to voltage and inversely proportional to resistance.

PARALLEL CIRCUIT:

A circuit in which two or more loads are connected side by side and are controlled by the same switch, but operate independently of each other. This arrangement provides full electrical potential (voltage) to all portions of the circuit.

POSITIVE CHARGE:

An electrical charge with fewer electrons than normal.

POTENTIOMETERS:

Another type of variable resistor, with three connections, one at each end of the resistance and one connected to a sliding contact with the resistor.

POWER:

Rate of doing work.

RELAY:

Is an electric switch that allows a small current flow to control a much larger one. It consists of a control circuit and a power circuit.

REMOTE GROUNDS:

Are used where the component itself is not grounded, or where remote ground is used to control the component (for example, reversible motors, some instrument panel warning lights). Ground designation is the letter G followed by a number (for example, G-404).

RESISTANCE:

Is the opposition to current flow offered by a load, or other part of circuit.

RESISTOR:

A device made of carbon or wire that presents a resistance to current flow.

GLOSSARY

RHEOSTATS:

One type of variable resistor with two connections: one to the fixed end of a resistor and one to a sliding contact with the resistor.

SERIES CIRCUIT:

A circuit in which its separate components are connected successively end to end to form a single path for the current to flow.

SERIES-PARALLEL CIRCUIT:

Is a combination of series and parallel. It has two or more loads in parallel, plus an additional load or loads in series.

SIGNAL:

Electrical quantity that conveys information from one point to another.

SINGLE WIRE:

In the automobile, wire is used principally on the hot (positive) side of the circuit. The grounded side is principally the chassis metal. Thus, automobile circuits are generally classified as single-wire, referring to the hot side.

SOLENOIDS:

Are electromagnets with movable cores used to translate electrical current flow into mechanical movement.

STEPPED OR TAPPED RESISTORS:

Have two or more fixed values, available by connecting wires to several taps of the resistor.

SWITCH:

A mechanical or electrical device that completes or breaks the path of the current or sends it over to a different path. The switch opens (off) and closes (on) the circuit.

TEMPERATURE-SENSITIVE SWITCH:

Usually contains a bimetallic element heated either electrically or by some component where the switch is used as a sensor.

TWO-WIRE CIRCUITS:

Use a second wire instead of chassis ground for the return side of the circuit.

VARIABLE RESISTORS:

Are designed to have a range of resistances available through two or more taps and a control.

VOLTAGE (VOLT):

The unit of measurement for electrical pressure.

VOLTAGE DROP:

The voltage developed between the terminals of a circuit component by the flow of current through the resistance of that part.

VOLTMETER:

Is an electric meter used to measure electromotive force (EMF).

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